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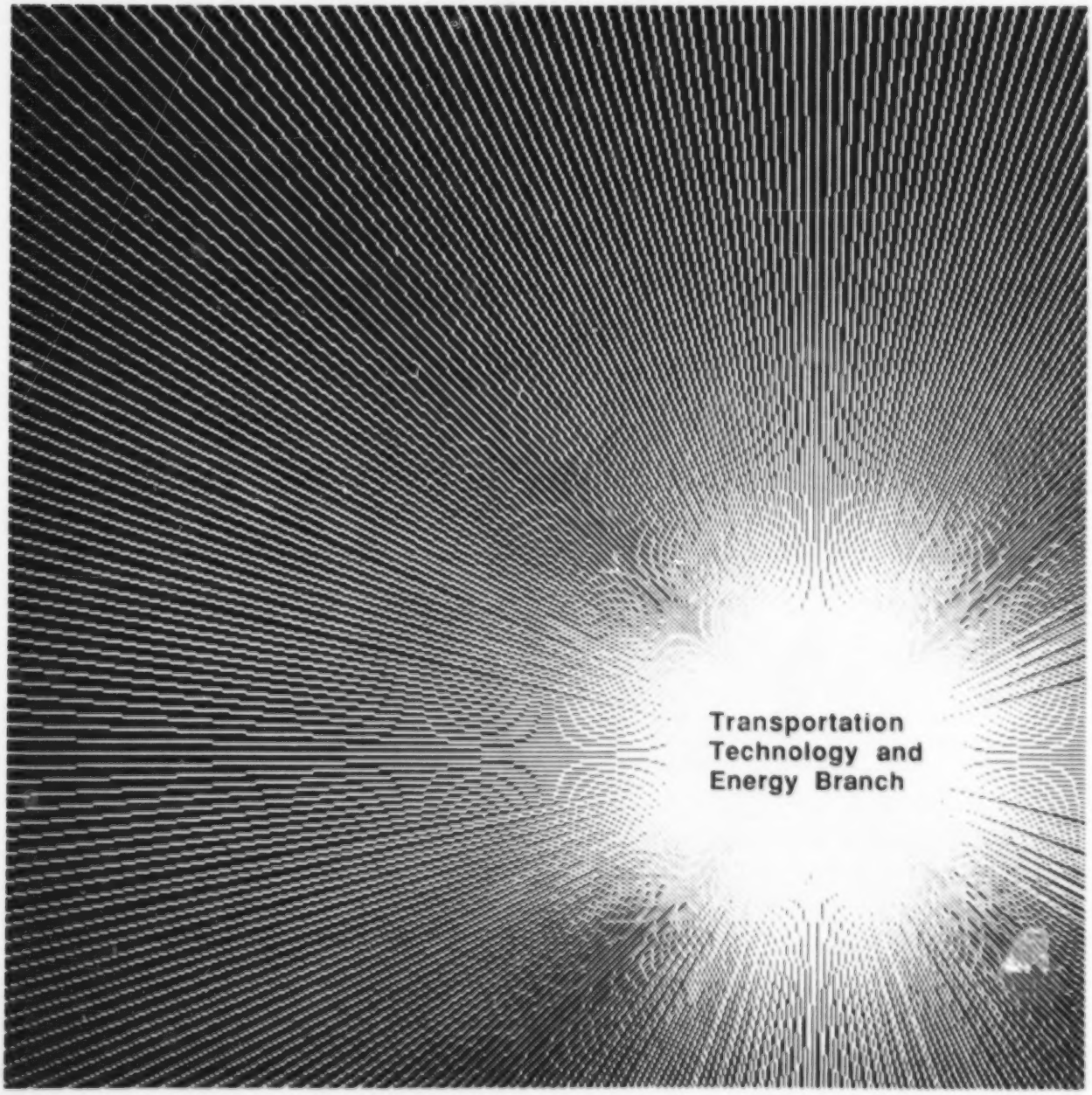

92-00468/

Diesel-Fired Coolant Heaters: A Preliminary Evaluation on Conventional Transit Buses for the Town of Markham

AT-91-02

Technical Report Documentation Page

Diesel-Fired Coolant Heaters: A Preliminary Evaluation on Conventional Transit Buses for the Town of Markham

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and
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Report No.: AT-91-02

Date: October 1991

Published by: Transportation Technology and Energy Branch
Ministry of Transportation

Abstract: An evaluation of four competing diesel-fired coolant heaters sold in Ontario was carried out over the first two months of 1991. These units, which consume diesel fuel from the vehicle's fuel tank to heat the engine coolant, were installed in conventional transit buses.

The heaters were expected to perform two functions during cold weather operation. The first was adequate and timely engine pre-heating, whereby the engine coolant is brought up to some temperature above ambient conditions before the engine is started. The second function of the auxiliary heaters was to help maintain a comfortable interior temperature once the bus is operating on its route.

The results of this evaluation with respect to engine pre-heating suggest significant cost savings can be brought about by the reduction of engine idling under cold-start conditions. Benefits, however, were not evident in this evaluation with respect to using the heaters as an aid to maintaining a higher passenger compartment temperature.

Key words: Heaters, coolant heaters, diesel-fired coolant heaters, Markham, Webasto, Alltec, Espar, transit buses, fuel conservation, winter storage, outside storage

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Diesel-Fired Coolant Heaters: A Preliminary Evaluation on Conventional Transit Buses for the Town of Markham

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Published by:

Transportation Technology and Energy Branch
Ministry of Transportation of Ontario

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Technical Publications (TT&E Branch)
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Canada M3M 1J8
(416) 235-3466

October 1991

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ACKNOWLEDGEMENTS

The author wishes to thank a number of people who have assisted in this project. At Miller Transit, which is the operator of Markham's conventional bus fleet, thanks to Mr. Robin Brown, Operations Manager and Mr. Alfonso Demilio, Head of Maintenance. As well, Mr. Don Gordon, General Manager, Markham Transit and Mr. Brian Sheardown of the Ministry of Transportation of Ontario (MTO) Transit Office deserve recognition. At MTO's Vehicle Technology Office, Mr. Jeff Turner, Project Research Engineer, and Mr. Howard Sahsuvar, Research Technician, have made significant contributions.

Without everyone's patience, cooperation and constructive suggestions, this evaluation would not have been possible.

EXECUTIVE SUMMARY

A preliminary evaluation of diesel-fired coolant heaters on conventional transit buses was carried out over the first two months of 1991. These units consume diesel fuel from the vehicle's fuel tank to heat the engine coolant.

The use of diesel-burning coolant heaters has been investigated by the ministry's Transit Office as one way to facilitate outdoor storage of bus fleets during the winter months. The ministry's Vehicle Technology Office was asked to assist in the technical evaluation of this concept.

The heaters were expected to perform two functions. The first was adequate and timely engine pre-heating, whereby the engine coolant is brought up to some temperature above ambient conditions before the engine is started. Without some sort of heating, many heavy-duty diesel engines will not crank, let alone fire, in cold weather conditions. The 40-foot Orion buses in the Markham fleet now use electrically powered block and oil pan heaters of approximately 2 kW total capacity to pre-heat their DDC 6V92 engines. Even with the electric heaters, bus maintenance staff find it necessary to start and idle each bus engine for a minimum of two hours every morning before the operator arrives to drive the bus. On some very cold days, the engines are idled continuously overnight. Therefore, any reduction in engine idling time brought about by using diesel-fired coolant heaters will result in a decrease of the net fuel consumed by each bus. Other benefits, which would be more difficult to quantify, include a net reduction in exhaust emissions along with a net reduction of maintenance costs. The latter benefit would be the difference between the maintenance cost reduction on the engine brought about by the use of the heater (longer life on engine components) and the maintenance requirements of the heater itself.

The second function of the auxiliary heaters was to help maintain a comfortable interior temperature once the bus is operating on its route. Markham has received complaints from its patrons of the buses being too cold. This problem may be the result of the bus interior not being brought up to an adequate temperature before picking up its first passengers in the morning or the engine not being able to reject enough heat into the coolant, especially when idling.

Three suppliers of coolant heaters furnished and installed four units for this evaluation. In alphabetical order they were: Alltec 2000 Inc., which supplied the Wintermiser 7501 (10.3 kW nominal capacity); Trans Artik of Ontario Inc., which supplied the Espar D12W (12.0 kW nominal capacity); and Webasto Heater Division of Schmitter Car Heating Ltd., which supplied the Webasto DBW 2010 (11.6 kW nominal capacity) and the Webasto DBW 2020 (23.3 kW nominal capacity). The heaters were installed in four identical 1988 model buses.

The results of this evaluation suggest that use of the heaters as an engine pre-heat device promises significant cost savings. Reduced fuel costs are brought about by the reduction of engine idling under cold-start conditions. In the case of the Webasto DBW 2020 unit, up to 70% of the fuel consumed in idling the engine prior to leaving the bus yard can be saved through the use of coolant heaters. This represents a cost saving of $6.23 per operating day. With the Espar D12W unit, between 56% and 64% of the fuel consumption attributed to idling the engine prior to leaving the bus yard can be saved, representing a cost saving of between $4.99 and $5.66 per operating day. Similarly, the Webasto DBW 2010 unit will save between 55% and 61% of the fuel used prior to leaving the bus yard, representing a cost saving of between $4.91 and $5.36 per operating day. Other quantifiable cost savings were $2.42 per operating day for each of the four units, which arises from eliminating electrical power consumed in operating electric block and oil pan heaters. An additional $1.27 per unit per operating day can be saved with the Webasto DBW 2020 through the elimination of some labour requirements in the bus yard each morning due to the unit's rapid heating time.

The Alltec unit was inoperative for a significant portion of the evaluation period. Furthermore, when it was operational, it was consistently unable to reach the target coolant temperature of 70°C within two hours. Because of this limited availability and performance, a similar analysis of fuel savings for the Alltec unit was based on estimated values, resulting in a fuel saving of 61% and $5.36.

When the quantified benefits of each unit were compared to the unit's price, in the form of a simple payback analysis, the Alltec unit had the shortest payback period, at 247 operating days. The Espar D12W had the next lowest payback period: between 308 and 336 operating days. It was followed by the Webasto DBW 2020 with 377 operating days (432 operating days if this unit's labour savings are eliminated) and by the Webasto DBW 2010 with between 456 and 484 operating days. The same relative ranking occurs if one calculates the Internal Rate of Return (IRR) of the four units. The highest IRR occurs for the Alltec unit (30%); it is followed by the Espar unit (20-23%); the Webasto 2020 (13% without labour, 17% with labour cost savings) and the Webasto 2010 (10-12%). One should remember that the economic analysis of the Alltec unit was based on estimated performance values due to the limited availability and performance of this unit. The relatively high rankings achieved by this unit suggest that it has the potential for value if the manufacturer is able to improve the unit's performance to estimated values while maintaining the price.

The results of this evaluation with respect to the potential benefits of using diesel-fired coolant heaters as an aid to maintaining a higher passenger compartment temperature were not evident. However, from the instrumented testing, it appears that the bus passenger compartment can be brought up to 20°C within 20 minutes at an ambient temperature of -8°C when using the Webasto DBW 2020 unit. Under similar conditions, the bus equipped with the Webasto DBW 2010 unit required 26 minutes

and the Espar D12W bus required 29 minutes. Again, because of the limited availability of the Alltec unit, the time required for this bus to reach an interior temperature of 20°C could not be determined.

This study was limited to the energy consumption impact of the coolant heaters. In a more comprehensive study, the various emergency shutdown systems of the heaters as well as the accuracy and reliability of the timers should be assessed. There is also the issue of determining the adequacy of the heaters at temperatures below -8°C, which was the lowest temperature encountered in this evaluation. Other issues are the exhaust emissions of the heaters and their maintenance requirements.

1/ INTRODUCTION

Outdoor storage of transit buses during the winter months is being looked at by MTO's Transit Office as a possible way of reducing capital costs for transit operators across Ontario.

However, outside storage is not as simple as parking the buses outside overnight and ensuring that they have an engine coolant with an adequate freezing point. Two specific problems with cold weather storage have been identified by transit systems. One is simply the ability to start the diesel engine of the bus on cold days. The second is the issue of ensuring a comfortable temperature in the passenger compartment of the bus, particularly during the first minutes of revenue service. It is these two issues which this study examines. Additional problems with winter storage include snowdrifts and freezing rain.

At Markham Transit, outside storage has been the rule for many years. Currently, Markham and its contracted operator, Miller, cope during the winter months by using electrically powered block and oil pan heaters with a typical combined capacity of 2 kW. With this approach, the buses are started and idled for a minimum of two hours before they are taken out on the road in the morning. The reason for this is twofold. First, this is done to ensure that the engines do indeed start, as even with the electrical heating, engine cranking and compression-ignition become difficult processes at low temperatures. In fact, Miller will idle the engines continuously overnight on very cold days. Secondly, the two-hour warmup helps to ensure that the bus interior is warm for the day's first passengers. Obviously, this extended idling is a waste of fuel, causes unnecessary engine wear, and contributes to air pollution.

One possible solution to the problems associated with cold storage is being investigated at Mississauga Transit with financial support from the ministry. It involves circulating hot coolant through each bus while the bus is plugged in at a central facility. Coolant circulates not only through the engine but also through a coolant-to-air heat exchanger, which uses natural convection to continuously heat the passenger compartment. The coolant is heated by a centrally installed boiler, typically sized for 100 buses.

The ministry's Transit Office is investigating alternative approaches for smaller transit properties. These alternatives should not require the construction of a permanent facility and should involve a capital investment which is incremental with each bus added to the fleet. Diesel-fired coolant heaters meet these requirements. They have been in use for a number of years, particularly in Class 8 trucks. They offer, in addition to ensuring that the coolant is warm prior to starting the engine, the possibility of carrying an on-board heat source in case the heat rejected by the diesel engine is insufficient to maintain a comfortable passenger compartment temperature during bus operation. MTO's Vehicle Technology Office of the Transportation Technology and Energy Branch was asked to help conduct the evaluation since it has experience with vehicle testing as well as having an instrumentation laboratory.

2/ DESCRIPTION OF BUSES AND HEATER UNITS

Six identical 40-foot Orion buses were set aside by Miller Transit for the evaluation. They are unit numbers 2027, 2030, and 2033 through 2036. Table 1 lists some characteristics of the buses. From the factory, the buses are equipped with two coolant-to-air heat exchangers, mounted in the front and in the middle of the bus. Both heater cores are connected in parallel to the engine and an electrically powered centrifugal pump is used to feed coolant to the heat exchangers (Figure 1). The front heater core is rated at 14 kW while the rear unit is rated at 32 kW at standard conditions (which assume a coolant temperature of 80°C and a coolant flow rate of 27 L/min). The buses are equipped with the "warm wall" option which ducts heat along the interior wall of the coach onto passenger windows.

Three manufacturer/distributors of the auxiliary diesel-fired heaters were involved in the evaluation. They were Alltec 2000 Inc., which builds the Wintermiser brand of heaters, Trans Artik of Ontario Inc., representing Espar, and the Webasto Heater Division of Schmitter Car Heating Ltd. Each company was asked to recommend a unit for the application which covers a requirement for engine pre-heating as well as providing supplementary heat while the bus is in operation.

Both Alltec and Trans Artik recommended units whose nominal heating capacity was in the range of 10 to 12 kW. Webasto, however, recommended a unit with an output of 23 kW, approximately twice the output of the others. In order to compare similar equipment from the three manufacturers, Webasto agreed to supply an 11.6 kW unit as well as their originally recommended unit. The remaining two buses were left unmodified and were used as controls.

Table 2 outlines specifications for the four units. These specifications were derived from the manufacturers' literature. Note that the current draws in Table 2 include the current consumed by standard coolant circulation pumps. In the case of the Espar and the large Webasto units, company representatives reported that they had installed pumps with higher capacities than those found in typical installations. All three manufacturers supplied count-down timers with their units. These devices enable starting the heaters without operator assistance. However, during the trial period, the four heater units were operated manually and the operation of the timers was not evaluated.

Figure 2 is a sketch of a typical coolant heater. It operates similarly to a household oil-fired furnace. Combustion air is drawn into the unit via the blower fan where it mixes with fuel and ignites, heating the combustion chamber. An ignition device comes on when the heater is first started in order to establish a flame. The device also comes on whenever flame is lost during operation. Extinguishing the flame involves cutting off the fuel supply. A circulation pump forces coolant into the jacket surrounding the combustion chamber. A temperature sensor at the coolant jacket causes the heater to cycle between typical temperatures indicated in Table 3. When the flame is

extinguished because of the temperature sensor, the coolant circulation pump continues to run. At the same time, the blower fan runs for approximately two minutes in order to cool down the burner and purge gases from the combustion chamber. Shutting down the unit through the control panel shuts down the coolant circulation immediately but causes the blower fan to run through the purge cycle.

Safety features of the heater unit include a secondary temperature sensor (often called an "overheat switch") which shuts down the heater if the temperature of the coolant jacket exceeds a pre-set temperature. This temperature would be above the upper bound set by the primary temperature sensor. Once the secondary temperature sensor is tripped, it must either be reset manually or replaced before the burner can be restarted. A typical reason for the coolant jacket overheating would be poor coolant circulation due to a defective circulation pump or coolant leakage. Another feature is low voltage detection. Since the burner unit and its coolant circulation pump draw their electric power from the vehicle's batteries, extensive operation of the heater could drain the batteries to the point where the vehicle's electric starter cannot operate. For this reason, the heater will shut down if the battery voltage drops below 10 V. A third feature is a photoelectric flame detector installed in the combustion chamber. This sensor works in conjunction with the control logic of the heater which stops attempts to establish the flame if no flame is detected after a set time period.

Some differences in equipment details between the four heaters used in this evaluation are in the areas of ignition and fuel metering. The Alltec unit uses a glow plug to help establish the flame while the Espar burner uses a combination device which produced sparks as well as being a glow plug. Both Webasto heaters use sparking to establish the flame. The Webasto units, however, also have a resistance heater for the fuel nozzle which activates at ambient temperatures below 0°C. In terms of fuel delivery and metering, both the Alltec and Espar units use an electric fuel pump mounted away from the burner unit. The pump is calibrated to deliver a known flow rate. In order to extinguish the flame, the fuel pump is turned off. Both Webasto units use a gear-type of fuel pump which is integral to the burner and is driven off the blower motor. Fuel metering in the Webasto heaters is by way of a calibrated nozzle. The continuous operation of the Webasto fuel pump requires a separate, return fuel line to the tank. An electric solenoid valve shuts off the fuel to the flame in the Webasto heaters.

3/ DESCRIPTION OF EVALUATION METHOD

Two parallel evaluations were carried out. Conducting controlled tests and acquiring operational experience were the two components of this evaluation that took place over the winter of 1990-91.

The first component involved a series of instrumented warmup tests which simulated cold-starting the heater-equipped buses after an overnight cold soak. In each test, the buses were instrumented to measure battery voltage, combined current draw of the burner unit and circulation pump, coolant temperature at the engine and at the outlet of the heater, along with the temperature of the bus interior. Readings were recorded by a Burr-Brown PCI Data Acquisition System in a form which can be processed on a microcomputer-based spreadsheet. The fuel consumption of each burner unit was assessed as well, by measuring the change in weight of a fuel reservoir. A total of nine warmup tests were performed.

Each test involved starting the four heaters simultaneously while observing the temperature of the coolant at the engine. Once the coolant reaches a temperature of 70°C, the engine of the bus is started at the same time as the heating system of the bus is turned on and the auxiliary heater is running. The test on each bus is stopped when the interior temperature of that bus reaches 20°C. The test results are in Section 4 of this report.

The second component was to obtain operational experience. The heater-equipped buses were put into revenue service along with the two control buses. As well as noting any operational difficulties with the four heaters, the drivers of all six buses recorded the temperature of the passenger compartment at fixed points along their routes. These temperature readings are in Section 4. Because of time constraints, it was impossible to set up and install an on-board data acquisition system to record parameters such as coolant temperature and passenger compartment temperature automatically.

4/ RESULTS OF EVALUATION

Figures 3 through 8 list typical data generated by the first of the nine warmup runs (tests). The relative performance of the four units remained constant throughout the nine runs.

Figure 3 presents the temperature of the coolant in the engine as a function of time. In this figure, each heater unit follows a characteristic curve which consists of three parts: warmup of the coolant to 70°C; an abrupt drop in temperature after the engine is started; and a gradual rise in temperature as the engine idles with the heater operating.

In the case of the Alltec-equipped bus, the unit was consistently unable to reach 70°C within the time capacity of the data acquisition system (approximately two hours or 7200 seconds). For this reason, it was decided to start the engine of the Alltec bus at a temperature of 55°C. This resulted in slow and difficult cranking when the ambient temperature was below 0°C.

Ideally, the engine should be started with as high a coolant temperature as possible short of the boiling point. The higher temperature of the engine block will help lower the viscosity of the oil and reduce frictional resistance. It will improve lubrication and reduce engine wear. Higher coolant and therefore combustion chamber temperature will aid the compression ignition process. Furthermore, the passenger compartment will warm up sooner once the engine is started. An engine starting temperature of 70°C was selected, since it is only 12°C below the operating temperature of the engine thermostat and since it is within the capabilities of three of the four heater units.

The Webasto model 2020 shows the fastest rise in engine temperature. It is followed in descending order by the Espar, Webasto 2010 and Alltec units.

The temperature-time profiles in Figure 3, up to the point of engine start-up, indicate that the heat losses to the environment rise as the warm-up period is prolonged. For instance, among the four heaters, the Webasto 2020 incurs the smallest heat losses. If there were no heat losses to the environment, the temperature-time profile would be a straight line with a constant slope proportional to the rate of heat supplied. The extent of divergence from this initial slope is indicative of the heat losses to the environment.

Figure 4 shows the coolant temperature near the outlet of the heater for the four units. The temperature-time relations follow the same shape as the curves in Figure 3 with the exception that there is a higher temperature at the heater outlet than at the engine. This difference is most noticeable just prior to engine start. For example, the Webasto model 2020 shows a temperature of approximately 81°C at this point, while in Figure 3 the temperature in the engine at the same time is 70°C. The Webasto model 2010 has the highest difference in temperatures, followed by the Webasto model 2020, Espar and Alltec units, in descending order.

This temperature difference between Figures 3 and 4 represents a heat loss in the system between the diesel-fired heater and the engine. Likely sources of this heat loss are the two coolant-to-air heat exchangers used to heat the passenger compartment and through which the hot coolant circulates. Even though the air blowers are not operated before the engine is started, natural convection could draw some heat away from the heat exchangers. Other sources of heat loss are the pipes that carry coolant along the sides of the bus.

Figures 5 through 8 represent typical current draw characteristics of the four heaters measured under the same conditions, in run number 1.

Figure 5 indicates current draw by the Alltec unit. When the unit is first started, current peaks at approximately 22 amps while the unit attempts to establish combustion. Current then stabilizes at approximately six amps during normal operation. Spikes in current occur as the flame extinguishes and the unit's glow plug comes on to re-establish the flame. When the engine starts, a jump of approximately one amp is observed. This effect was seen with all four units and is thought to be related to the vehicle's alternator coming on line.

Figure 6 shows a typical current draw profile with the Espar unit. It shows a peak current of approximately 29 amps during starting with a stable draw of approximately 18 amps during normal operation. Current draw increases by approximately three amps while the engine is running.

Figure 7 shows current draw with the Webasto model 2010 unit. Current is relatively stable at approximately 15 amps, with an increase of approximately two amps while the engine is running. No real peak is observed when the heater is started, probably because the ambient temperature of this run was above 0°C and as a result the nozzle heater probably did not come on. However, in other runs, (run number 6, for example) the Webasto 2010 showed a peak current of approximately 28 amps while starting. This peak lasted approximately five minutes.

Figure 8 is the current-time relation for the Webasto model 2020 unit. It shows a peak current of approximately 24 amps while starting and a stabilized current of approximately 17 amps just prior to engine start. During engine operation, the Webasto shows cycling between approximately 5 and 20 amps. This Webasto unit has also shown a peak current of approximately 33 amps while starting (in run number 6). This was a momentary spike, and the starting current settled down to approximately 28 amps for approximately two minutes.

Table 4 lists the electrical energy consumed by each of the four heaters just prior to the engine starting. The figures are derived from the area under the current-time curve. As will be addressed in Table 5 (time taken to reach 70°C), run number 2 was discarded for all four heaters. Also, the inability of the Alltec unit to reach 70°C within the time limits of the data acquisition system required an estimate of the electrical

energy that would have been consumed. This extrapolation is indicated by figures in brackets. Similarly, a problem with the measurement equipment in runs 3, 6, and 7 resulted in the Webasto DBW 2010 unit starting later than the others. In these runs, the Webasto DBW 2010 unit did not have sufficient time to reach 70°C. For this reason, the electrical energy consumption of the Webasto DBW 2010 unit was estimated as well.

Electric power for the heater is supplied by the buses' lead acid batteries. The energy drawn by the heater therefore has several implications on the battery. Repeated deep discharges of the battery would tend to reduce its life. Also, the storage capacity of a lead acid battery decreases with temperature. For these two reasons, it is desirable to minimize the electrical energy draw of the heater system while the engine is stopped. As shown in Table 4, the Webasto DBW 2020 heater had the lowest electrical energy consumption.

Table 5 lists the time required for each bus engine to reach 70°C. Run number 2 was dropped because of an improper cold soak of all four buses. In the case of the Alltec unit, the temperature-time curve was extrapolated to estimate how long the unit would have taken to reach 70°C if the data collection system had sufficient capacity. Similarly, the Webasto DBW 2010 unit was started late in runs 3, 6, and 7 due to fuel leaks caused by the installation of the consumption-measurement tank. As a result, the time taken for the Webasto 2010 to reach 70°C was estimated by extrapolation. In these three runs with the Webasto 2010, the engine was started at the same temperature as the Alltec: 55°C. The Alltec and Espar units in run 4 (also in run 6 onward for the Alltec unit) did not start.

Table 6 lists the fuel consumption in the remaining eight valid runs. Note that fuel consumption includes the total fuel consumed by the heater over a given run, including the time the heater is left running while the engine idles. In the case of the Alltec unit, the fuel consumption indicated in runs 1, 3, and 5 is an estimate of the fuel that would have been consumed by the heater if the engine had been allowed to reach 70°C. In this case, the engine had been started at 55°C. A similar situation exists for the Webasto 2010 in runs 6 and 7. N/A in this table signifies that fuel consumption information is not available, either as a result of the heater not operating (as with the case of the Alltec unit) or due to problems with the fuel measurement system.

Table 7 shows the time required for the bus interior to reach 20°C, once the engine is started. N/A in this table indicates that data were not applicable on a given run: either because the diesel-fired heater was not operational or because the air-operated doors of the bus were not sealing properly.

In terms of subjective experience with the heater-equipped buses operating in revenue service, the major occurrences related to the heaters not operating, as noted earlier. The Espar unit would not start on one occasion and it was out of service for

approximately one week until service representatives arrived. The Alltec unit was out of service for a significant portion of the test period.

The results of the driver-compiled interior temperature readings are presented in Table 14. This table includes results obtained with two control buses and the four heater-equipped buses on the Unionville and Markham express. The six buses were operated during the morning and afternoon rush-hour periods and returned to the Miller yard during mid-day. Each driver measured the interior temperature at two pre-determined points along the route. Average (mean) temperatures were calculated for each bus, as well as a statistical interval at the 95% level of confidence.

5/ DISCUSSION OF RESULTS

Looking at the results of the instrumented warmup tests, it becomes clear that the larger Webasto unit is able to heat the coolant considerably faster than the other three heaters. This was expected, since the Webasto DBW 2020 has roughly twice the heating capacity. The lowest ambient temperature encountered was -8°C (shown in Table 5). At this temperature, the Webasto DBW 2020 was able to bring the engine coolant temperature up to 70°C in 20 minutes. The Espar unit was the next fastest with a heating time of 70 minutes, followed by the Webasto DBW 2010 unit at 120 minutes. The Alltec unit was the slowest at heating up the coolant. This ranking corresponds to the rated capacities of the four heaters (shown in Table 2). In the three runs in which the Alltec unit was operational, it was unable to reach 70°C within the time limits of the data acquisition system and the engine was started (with difficulty) at a coolant temperature of 55°C. It is estimated that it would have taken approximately 145 minutes for the Alltec unit to warm up the engine to 70°C.

Once the bus engine was started, the bus equipped with the Webasto DBW 2020 was able to heat its interior to 20°C in 20 minutes, on a -8°C day (see Table 7). The Webasto DBW 2010 bus took 26 minutes while the Espar bus took 29 minutes. No reliable data were collected on the warmup of the Alltec bus interior in sub-zero temperatures on which to base an estimate. However, for the purposes of further analysis, one can take the mean time for the other two buses equipped with similar-capacity heaters (Espar and Webasto 2010). This yields an estimated warmup time of 28 minutes for the Alltec bus interior. During the portion of each run in which the bus interior was warmed up, problems with sealing doors were detected and they could account for differences between buses.

The fuel consumed by each heater during the engine pre-heating and interior warmup phases is outlined in Table 6. A noticeable spread was observed in the fuel consumption measurements for each heater. When taking the readings from days with ambient temperatures below zero, the Webasto DBW 2020 unit consumed between 1.4 and 1.5 L. The Espar heater consumed between 1.4 and 2.3 L while the Webasto DBW 2010 consumed between 2.1 and 2.7 L. The Alltec had a single point with a sub-zero ambient temperature and it consumed an estimated 1.9 L.

One can now make an estimate of the costs and benefits of using each of the four coolant heaters in an engine pre-warming situation. All numbers will be on a per-bus basis. A diesel fuel price of $0.50 per L and a price for electric power of $0.065 per kiloWatt-hour will be assumed. As well, labour costs will we estimated to be $25.30 per person-hour.

Quantifiable savings will include the elimination of electricity consumption since the installed 2-kW resistance heaters will not be connected. Each bus is normally plugged in for 93 hours per 7-day week. This works out to 18.6 hours of electricity per

operating day, of which there are five per week. Each bus will therefore save 37.2 kWh (or $2.42) of electric power per operating day.

The reduction of engine idling can be looked at next. Currently, the engine of each bus is idled at least two hours each morning (from 3 to 5 a.m.) prior to leaving for the morning rush hour period and approximately 1 hour before leaving for the afternoon rush hour. This represents a fuel consumption of 17.7 L per operating day using the conservative estimate of fuel consumption at idle of 5.9 L/hour (Table 1). Most likely, the actual fuel consumption at idle is higher given the low temperature of the engine and the fact that a fast-idle setting is often selected in winter operations.

One point concerning quantifiable cost savings was suggested by Miller staff and is specific to the Webasto DBW 2020. Since this unit was able to bring the coolant temperature to 70°C in less than half an hour, Miller will be able to eliminate the two person-hours of labour per morning it costs to start the bus fleet at 3 a.m. Even with the need to start the buses at 3 a.m. eliminated through the use of the coolant heaters, it will still be necessary to send in a person at 3 a.m. to ensure that all 10 to 12 kW capacity heaters have fired. With the Webasto DBW 2020, the people starting on the regular 5 a.m. shift can ensure that the heater has fired. Given the heater's short warm-up time, if the heater had not fired properly while un-attended, this personnel can attempt another start and still get the bus into service in a reasonable period of time. The two person-hours of labour can be estimated at a total of $50.60 per operating day. With a fleet of 40 buses, the labour savings will be $1.27 per unit per operating day.

Other benefits of the heaters which cannot be quantified would include increased life of engine starter motors due to lower cranking requirements. One would also tend to expect a general increase in engine life due to a simple reduction of idling time and the fact that the engine is started at a higher temperature than what the electric heaters can provide (70°C vs typically 20°C).

Table 8 outlines the calculation of how much fuel will be consumed each operating day through the use of the diesel heaters and the resulting savings over the present system of idling the bus engine for bus warmup. A conservative estimate is that typical winter days will have a temperature of -8°C. In the case of the Webasto DBW 2020, the heater will consume approximately 1.5 L. Idling the engine for 20 minutes will use an additional 2.0 L, for a total fuel consumption of 3.5 L. This is for the morning start when the engine and bus interior will be at ambient temperature. For the afternoon starting attempt, the bus will be warmer, and one can assume that this second starting attempt will consume 50% of the fuel of the morning start-up, or 1.8 L. This represents a total fuel consumption of 5.3 L per operating day with a bus equipped with the Webasto DBW 2020, or a reduction of 70% of the fuel consumed for bus warm-up. The 12.5 L of fuel not consumed represent a saving of $6.23 (shown in Table 8) per operating day.

A similar analysis with the Espar unit uses an input of between 1.4 and 2.3 L heater fuel consumption and an engine idling time of 29 minutes. It yields a fuel saving of between 56 and 64% over the present warm-up procedure, for a net fuel saving of $4.99 to $5.66 per operating day. An analysis with the Webasto 2010 unit uses an input of between 2.1 and 2.7 L heater fuel consumption and an engine idling time of 26 minutes. It yields a fuel saving of between 55 and 61% over the present warm-up procedure, for a net fuel saving of $4.91 to $5.36 per operating day.

In the case of the Alltec unit, the estimated heater fuel consumption of 1.9 L was combined with an engine idling time which was the mean for the Espar and Webasto 2010 units (28 min). This yielded an estimated fuel saving of $5.36 per operating day, or 61% over the present warmup procedure.

Table 9 summarizes the estimated cost savings per heater unit. The three items listed consist of the net fuel saved due to the use of the heater units, electrical power saved due to the elimination of the electrical block and oil pan heaters, and labour savings from the elimination of the need to bring in personnel early in the morning. Note that the last item is specific to the Webasto 2020 unit. Note also that due to availability problems with the Alltec unit, fuel savings data were based on estimated values. One can see that regardless of whether the labour savings are included or not, the Webasto DBW 2020 unit has the greatest daily cost savings. The other three units' savings overlap.

One cost associated with each of the units will be maintenance, both scheduled and otherwise. However, due to limited experience with the heater units, this item will not be quantified here.

The capital costs of the heater units should be considered as well. A recent call for tenders on heater units was made by Markham Transit. The resulting bids can be used as estimates for unit prices. Excluding provincial sales tax and federal G.S.T., the lowest quoted prices to supply and install 40 heater units were $77,017 for Alltec, $99,478 for Espar, $141,815 for the Webasto DBW 2010 and $149,551 for the Webasto DBW 2020. On a per-unit basis, this translates to $1,925, $2,487, $3,545, and $3,739 respectively.

Performing a simple payback analysis allows one to compare these estimated unit prices to the cost savings that were quantified earlier. Table 10 lists the expected payback periods for each of the four heaters, in operational days. Whether or not one accounts for the labour savings which are unique to the Webasto DBW 2020 unit, the relative ranking of the units is the same. The shortest payback period is 247 days for the Alltec unit. It is followed by the Espar unit (at a range between 308 and 336 operating days). The next unit is the Webasto DBW 2020 unit with either 377 or 432 operating days (depending on whether or not the labour savings are included). The unit with the longest payback period is the Webasto DBW 2010 with an expected payback period in the range of 456 to 484 operating days. One should keep in mind

however, that the cost savings figures for the Alltec unit are based largely on estimated performance values.

One can also account for the time value of money as the cost savings of the heaters occur over several years. Table 11 represents the net present value (NPV) of each heater. It assumes a heater life of 10 years, 80 service days per year (4 months at 20 days per month), an interest factor of 5%, and zero salvage value. The negative cash flow at the beginning of each column represents the purchase of the heater. The cost savings are assumed to occur at the end of each year. The entry for each year represents the discounted savings. If one includes the labour cost savings for the Webasto DBW 2020, the heater with the highest NPV ($2,881) is Alltec. The Espar ($2,504 to $2,090) and Webasto DBW 2020 ($2,389) tie for second place, while the Webasto DBW 2010 ($1,261 to $983) has the lowest NPV. If one omits the labour cost saving of the Webasto DBW 2020 (NPV of $1,604), the respective ranking is Alltec, Espar, Webasto 2020, and Webasto 2010.

Looking at the effect of changing the interest factor in the NPV calculation (Table 12), shows that even at 10% and 15%, the relative ranking of the four heaters stays the same, independent of whether or not the labour cost saving is included for the Webasto DBW 2020 heater. Similarly, calculating the internal rate of return (Table 13) gives the same relative ranking. However, the economic quantities for the Alltec unit depend on estimated performance figures.

In terms of maintaining the bus interior at a warmer temperature, the coolant heaters appear not to have a statistically significant effect. Table 14 shows that for each of the two points along the route, the confidence intervals of the four heater-equipped buses overlap with those of the two control buses. One should keep in mind that the buses are equipped with valves that regulate the flow of coolant to the main passenger compartment heat exchanger in response to interior temperature. Similarly, the interior temperature was not measured continuously to see transient effects such as the opening and closing of doors, nor was the coolant temperature measured. However, these results suggest a limited benefit of coolant heaters from the point of view of passenger comfort, in the Markham context.

6/ CONCLUSION

Most of this study focused on the effects of coolant heaters in an engine pre-heat situation. As such, there are definite, quantifiable benefits to using diesel-fired heaters under these conditions since engine idling is reduced. These benefits include net savings of up to 70% of the fuel used in idling the engine during warmup, or $6.23 in fuel costs per bus per operating day. A further $2.42 per bus per operating day can be saved by eliminating the electrical power consumed by the present electrical block heaters in each bus. In the case of the Webasto DBW 2020 unit, a further $1.27 in labour costs per day can be expected. Other benefits not quantified would include increased engine life due to starting the engine at an elevated temperature and the reduction of idling time.

The results of this study with respect to the potential benefits of using diesel-fired coolant heaters as an aid to maintaining comfortable passenger compartment temperatures were not evident. However, from the instrumented testing, it appears that the bus passenger compartment can be brought up to 20°C within 20 minutes at an ambient temperature of -8°C when using the Webasto DBW 2020 unit.

Further assessment is required for several issues. The first is determining the effects of temperatures of -20°C and below. Since the lowest temperature encountered during the evaluation was -8°C, no data exist as to the effectiveness of the heaters at such extremes. A second issue relates to assessing the reliability of the individual safety features of the heaters, such as the low voltage shut-off, the flame detector, and the overheat switch. Also, since the automatic timers were never operated, the accuracy and reliability of this component was never assessed. One final issue relates to the environmental benefits of the heaters, specifically their exhaust emissions versus elimination of engine idle exhaust and noise emissions.

Table 1/ Bus Characteristics

Model	40-foot Orion
Model Year	1988
Accumulated Mileage	180 000 to 220 000 km
Engine	DDC 6V92
Coolant Thermostat Rated Temperature	82°C *
Coolant Capacity	92 L *
Electrical System	12V, 2 batteries, 205 AH capacity each *
Fuel Consumption at Normal Idle	5.9 L/h *

Note: * Indicates information was obtained from manufacturers' literature.

Table 2/ Heater Specifications from Manufacturers' Literature

Heater Model	Installed In Bus No.	Nominal Heat Output (kW)	Continuous Fuel Consumption (L/h)	Current Draw @ 12V Start/Run (Amps)
Alltec Wintermiser 7501	2033	10.3	1.10	23/6
Espar D12W	2034	12.0	1.65	18/8
Webasto DBW 2010	2035	11.6	1.50	18/7
Webasto DBW 2020	2036	23.3	3.00	30/19

Note: Current draw figures include "standard" coolant circulation pump.

Table 3/ Heater Operating Temperatures Derived from Manufacturers' Literature

Heater Model	Coolant Temperature Range (°C)
Alltec Wintermiser 7501	60 – 82
Espar D12W	81 – 90
Webasto DBW 2010	68 – 75
Webasto DBW 2020	68 – 75

Table 4/ Electrical Energy Consumed Prior to Engine Start

Run No. and Date	Ambient Temperature (°C)	Electrical Energy Consumed Prior to Engine Start (Amp-hr)			
		Alltec Wintermiser	Espar D12W	Webasto DBW 2010	Webasto DBW 2020
1/Jan 19	4	(16)	15	20	5
3/Jan 26	- 8	(44)	N/A	(24)	8
4/Jan 27	- 6	N/A	N/A	27	6
5/Feb 5	7	(15)	10	16	3
6/Feb 16	- 7	N/A	18	(30)	6
7/Feb 17	- 2	N/A	14	(25)	6
8/Feb 23	- 8	N/A	18	28	5
9/Feb 24	- 2	N/A	15	26	6

Note: N/A = Data not available
( ) = Value was estimated

Table 5/ Time to Reach 70°C

Run No. and Date	Ambient Temperature (°C)	Time for Engine to Reach 70°C (Minutes)			
		Alltec Wintermiser	Espar D12W	Webasto DBW 2010	Webasto DBW 2020
1/Jan 19	4	(132)	45	80	17
3/Jan 26	- 8	(145)	70	(110)	20
4/Jan 27	- 6	N/A	N/A	100	20
5/Feb 5	7	(125)	40	65	12
6/Feb 16	- 7	N/A	70	(120)	20
7/Feb 17	- 2	N/A	57	(95)	20
8/Feb 23	- 8	N/A	70	120	20
9/Feb 24	- 2	N/A	60	105	20

Note: N/A = Data not available
( ) = Value was estimated

Table 6/ Fuel Consumed During Run

Run No.	Ambient Temperature (°C)	Fuel Consumed During Run (L)			
		Alltec Wintermiser	Espar D12W	Webasto DBW 2010	Webasto DBW 2020
1	4	(1.8)	1.5	1.9	1.2
3	- 8	(1.9)	1.4	N/A	1.4
4	- 6	N/A	N/A	N/A	N/A
5	7	(1.8)	0.9	1.6	1.0
6	- 7	N/A	2.3	(2.6)	N/A
7	- 2	N/A	1.8	(2.1)	1.5
8	- 8	N/A	2.0	2.7	N/A
9	- 2	N/A	1.5	2.6	N/A

Note: N/A = Data not available
( ) = Value was estimated

Table 7/ Time for Bus Interior to Reach 20°C

Run No.	Ambient Temperature (°C)	Time for Bus Interior to Reach 20°C (Minutes)			
		Alltec Wintermiser	Espar D12W	Webasto DBW 2010	Webasto DBW 2020
1	4	17	15	15	11
3	- 8	N/A	N/A	N/A	N/A
4	- 6	N/A	N/A	N/A	N/A
5	7	17	N/A	15	10
6	- 7	N/A	33	22	20
7	- 2	N/A	27	23	20
8	- 8	N/A	29	26	20
9	- 2	N/A	27	N/A	18

Note: N/A = Data not available

Table 8/ Summary of Calculated Fuel Savings

Unit	Morning Start				Afternoon Fuel Consumption (L)	Daily Fuel Consumption (L)	Daily Fuel Savings		
	Heater Consumption (L)	Engine		Total Consumption (L)			L	%	$
		Time (min)	Consumption (L)						
Alltec	1.9	28	2.8	4.7	2.3	7.0	10.7	61	5.36
Espar	1.4 – 2.3	29	2.9	4.3 – 5.2	2.1 – 2.6	6.4 – 7.7	11.3 – 10.0	64 – 56	5.66 – 4.99
Web 2010	2.1 – 2.7	26	2.6	4.7 – 5.3	2.3 – 2.6	7.0 – 7.9	10.7 – 9.8	61 – 55	5.36 – 4.91
Web 2020	1.5	20	2.0	3.5	1.8	5.3	12.5	70	6.23

Note: For Alltec, daily fuel savings is based on an estimate of heater fuel consumption and engine idle time.

Table 9/ Summary of Estimated Cost Savings

Unit	$ Savings Per Operating Day			Total	
	Fuel	Electricity	Labour	w/Labour	w/o Labour
Alltec	5.36	2.42	0	7.78	7.78
Espar	5.66 – 4.99	2.42	0	8.08 – 7.41	8.08 – 7.41
Web 2010	5.36 – 4.91	2.42	0	7.78 – 7.33	7.78 – 7.33
Web 2020	6.23	2.42	1.27	9.92	8.65

Note: For Alltec, fuel saving is based on an estimate of heater fuel consumption and engine idle time.

Table 10/ Summary of Unit Prices and Payback Periods

Unit	Unit Price ($)	Payback Period (operating days)	
		w/Labour	w/o Labour
Alltec	1,925	247	247
Espar	2,487	308 – 336	308 – 336
Web 2010	3,545	456 – 484	456 – 484
Web 2020	3,739	377	432

Note: For Alltec, the payback period is based on an estimate of heater fuel consumption and engine idle time.

Table 11/ Summary of Net Present Value Calculation, Interest Factor = 5%, Service Days/Year = 80

Year	Alltec ($)	Espar ($)		Webasto 2010 ($)		Webasto 2020 ($)		
	7.78	8.08	7.41	7.78	7.33	9.92	8.65	Daily
	622.40	646.40	592.80	622.40	586.40	793.60	692.00	Yearly
0	(1,925.00)	(2,487.00)	(2,487.00)	(3,545.00)	(3,545.00)	(3,739.00)	(3,739.00)	
1	592.76	615.62	564.57	592.76	558.48	755.81	659.05	
2	564.54	586.30	537.69	564.54	531.88	719.82	627.66	
3	537.65	558.38	512.08	537.65	506.55	685.54	597.78	
4	512.05	531.79	487.70	512.05	482.43	652.90	569.31	
5	487.67	506.47	464.47	487.67	459.46	621.81	542.20	
6	464.44	482.35	442.36	464.44	437.58	592.20	516.38	
7	442.33	459.38	421.29	442.33	416.74	564.00	491.79	
8	421.26	437.51	401.23	421.26	396.90	537.14	468.37	
9	401.20	416.68	382.12	401.20	378.00	511.56	446.07	
10	382.10	396.83	363.93	382.10	360.00	487.20	424.83	
NPV	2,881.01	2,504.33	2,090.44	1,261.01	983.03	2,388.97	1,604.44	NPV

Note: For Alltec, the net present value is based on an estimate of heater fuel consumption and engine idle time.

Table 12/ Net Present Value Calculation Based on Three Interest Factors, Service Days/Year = 80

Interest Factor %	Alltec ($)	Espar ($)		Webasto 2010 ($)		Webasto 2020 ($)		
	7.78	8.08	7.41	7.78	7.33	9.92	8.65	Daily
	620.00	646.40	592.80	622.40	586.40	793.60	692.00	Yearly
5	2,881.01	2,504.33	2,090.44	1,261.01	983.03	2,388.97	1,604.44	
10	1,899.38	1,484.85	1,155.50	279.38	58.17	1,137.33	513.04	NPV
15	1,198.68	757.13	488.13	(421.32)	(601.99)	243.49	(266.01)	

Note: For Alltec, the net present value is based on an estimate of heater fuel consumption and engine idle time.

Table 13/ Summary of Internal Rates of Return (IRR)

Unit	IRR %
Alitec	30
Espar	23 – 20
Webasto 2010	12 – 10
Webasto 2020	17 – 13

Note: For Alitec, the IRR is based on an estimate of heater fuel consumption and engine idle time.

Table 14/ Interior Temperature of Bus During First Six Weeks of Operation

Bus Number	Temperature 1 (°C)			Temperature 2 (°C)		
	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit
2027 (Control)	21.7	22.4	21.1	21.7	22.4	21.0
2030 (Control)	21.7	22.9	20.6	22.0	23.0	20.9
2033 (Alitec)	23.6	24.3	22.9	23.1	23.8	22.3
2034 (Espar)	20.3	21.2	19.4	20.7	21.2	19.4
2035 (Web 2010)	21.0	21.7	20.2	20.8	21.6	20.0
2036 (Web 2020)	23.0	24.0	22.0	23.2	24.6	21.8

Note: Temp 1 and Temp 2 refer to the interior temperature measured with the bus stationary at each of two points along a route. For each group of temperatures, the table shows the corresponding mean temperature as well as a calculated 95% confidence interval. (upper & lower limit)

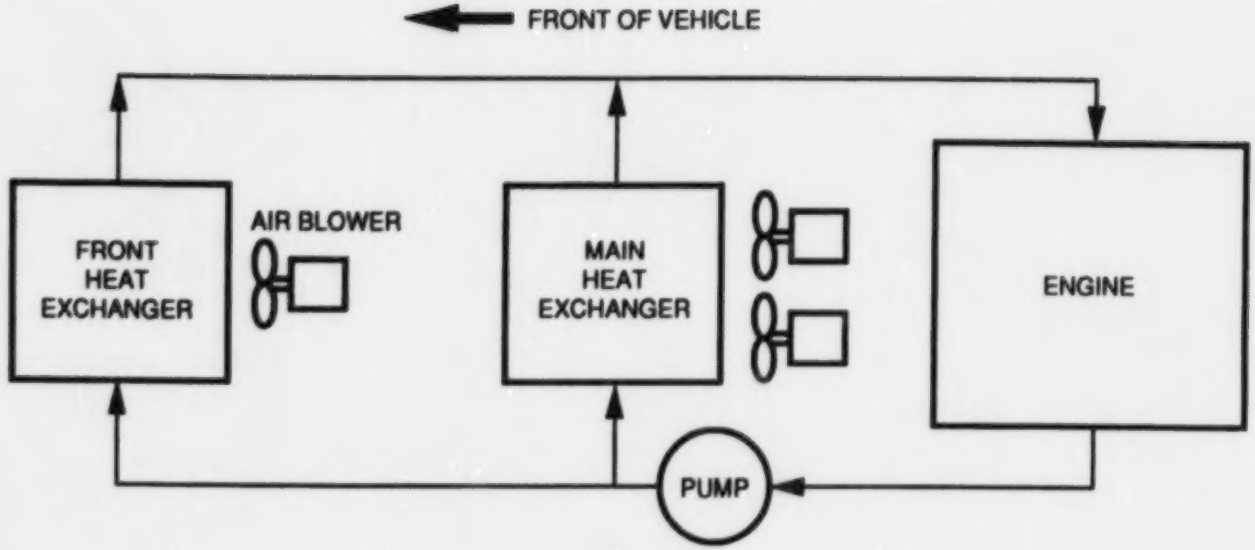

Figure 1/ Sketch of Coolant Circulation in Un-modified Bus

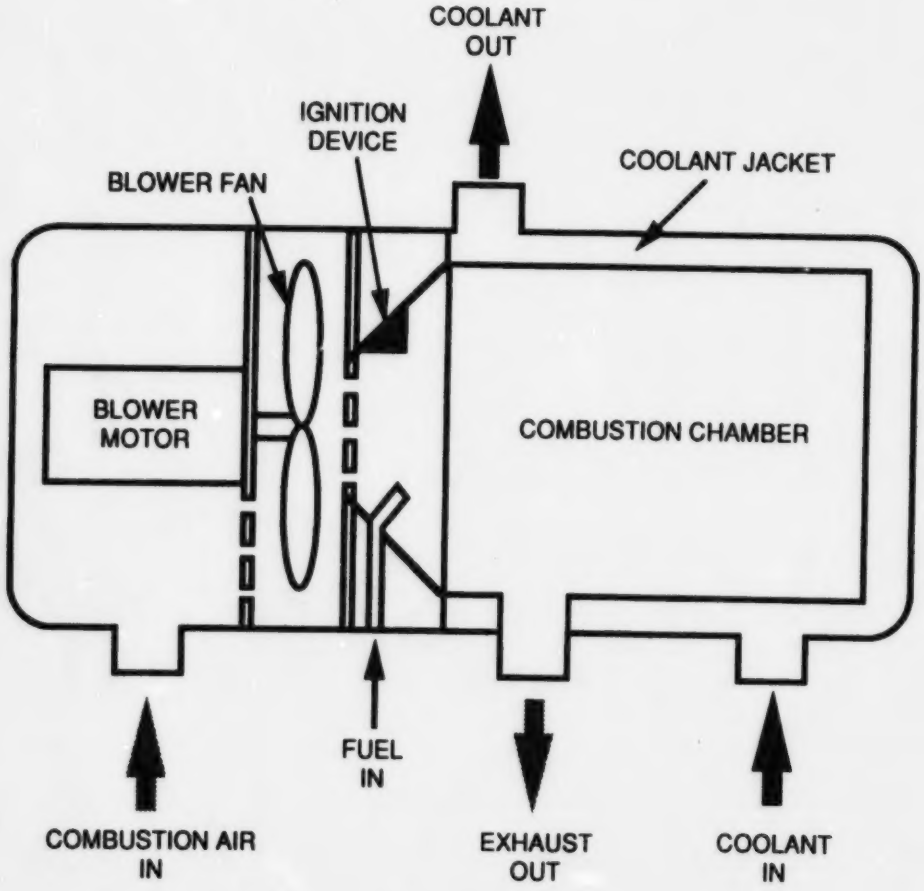

Figure 2/ Sketch of Typical Coolant Heater

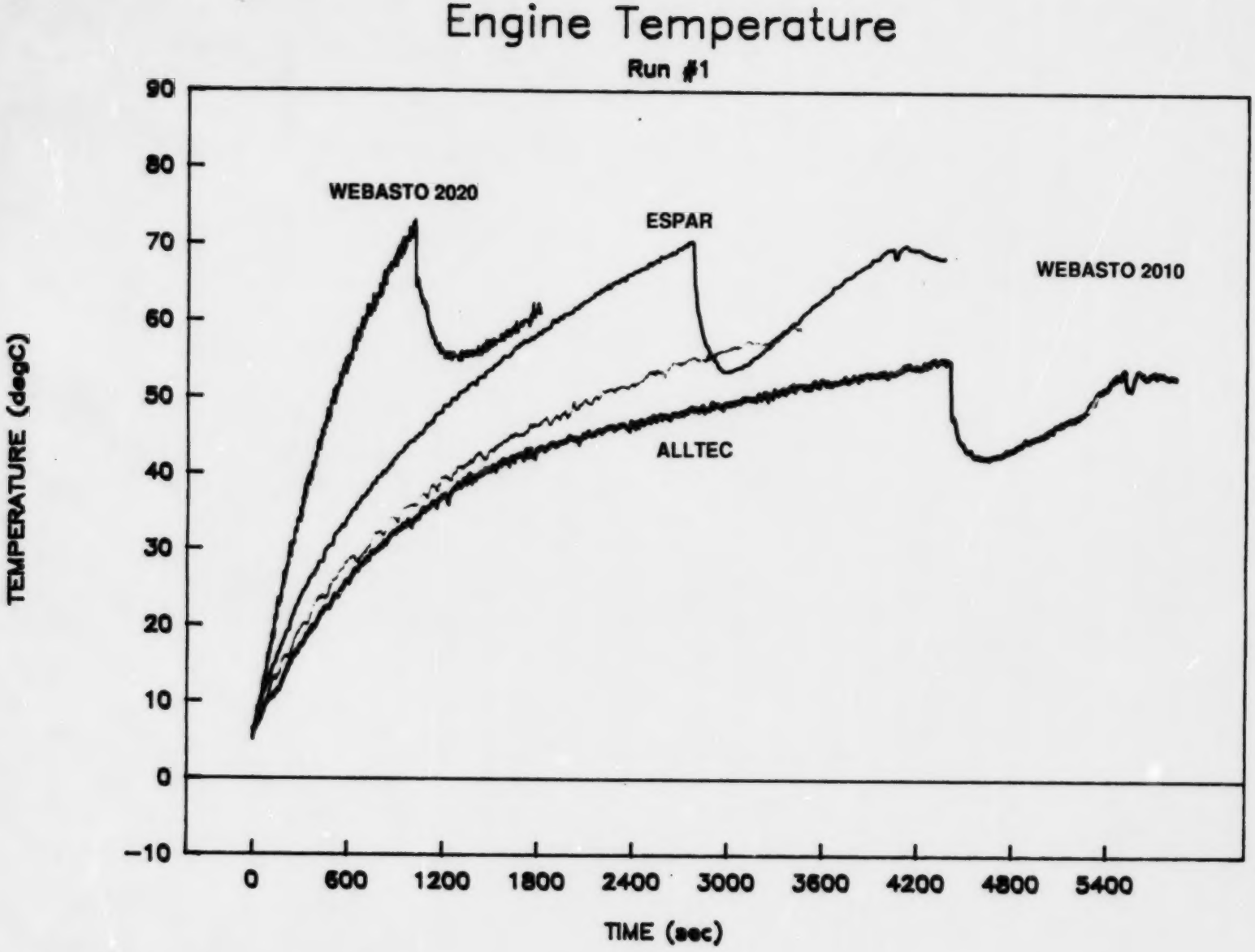

Figure 3/ Typical Engine Temperature Curve

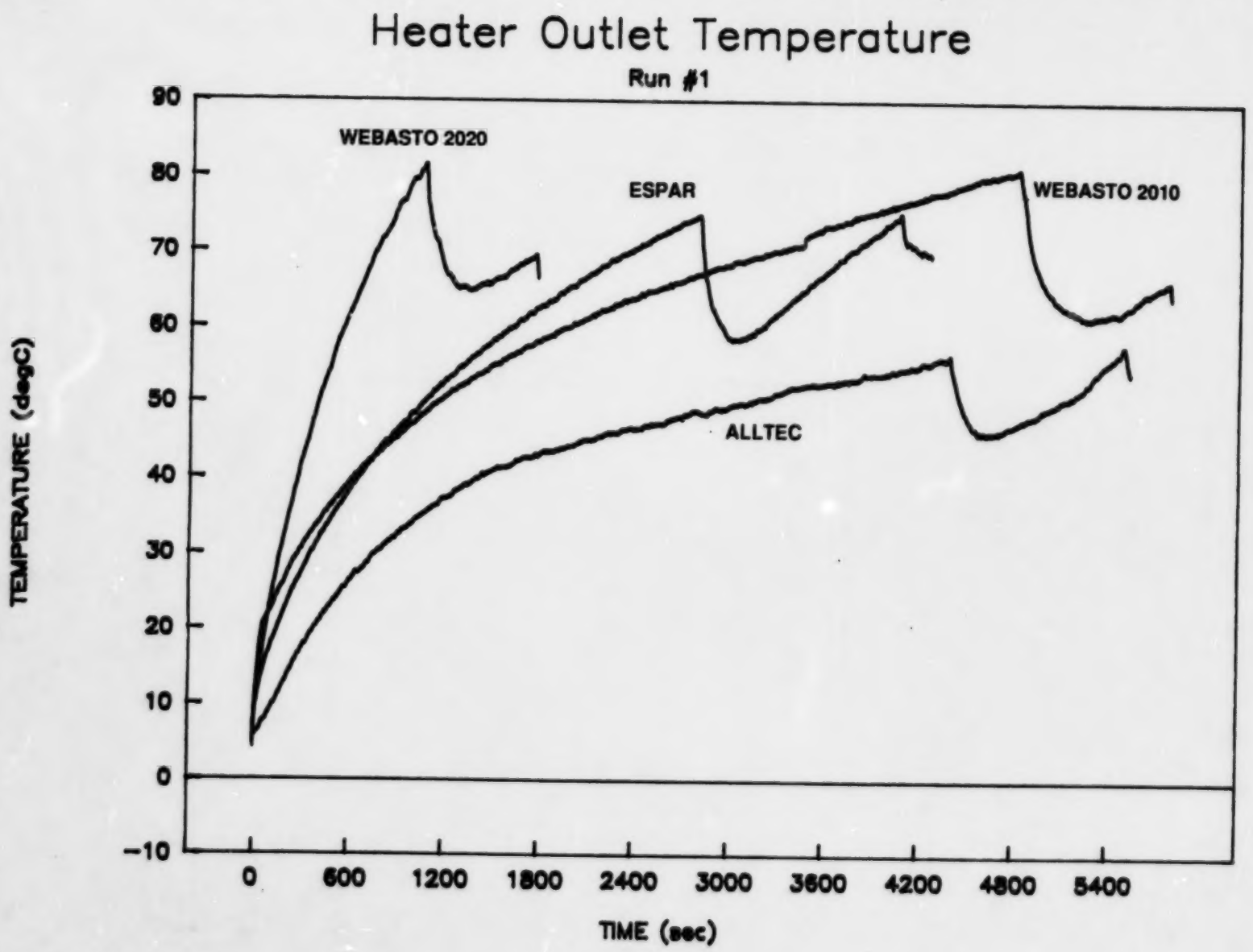

Figure 4/ Typical Heater Outlet Temperature Curve

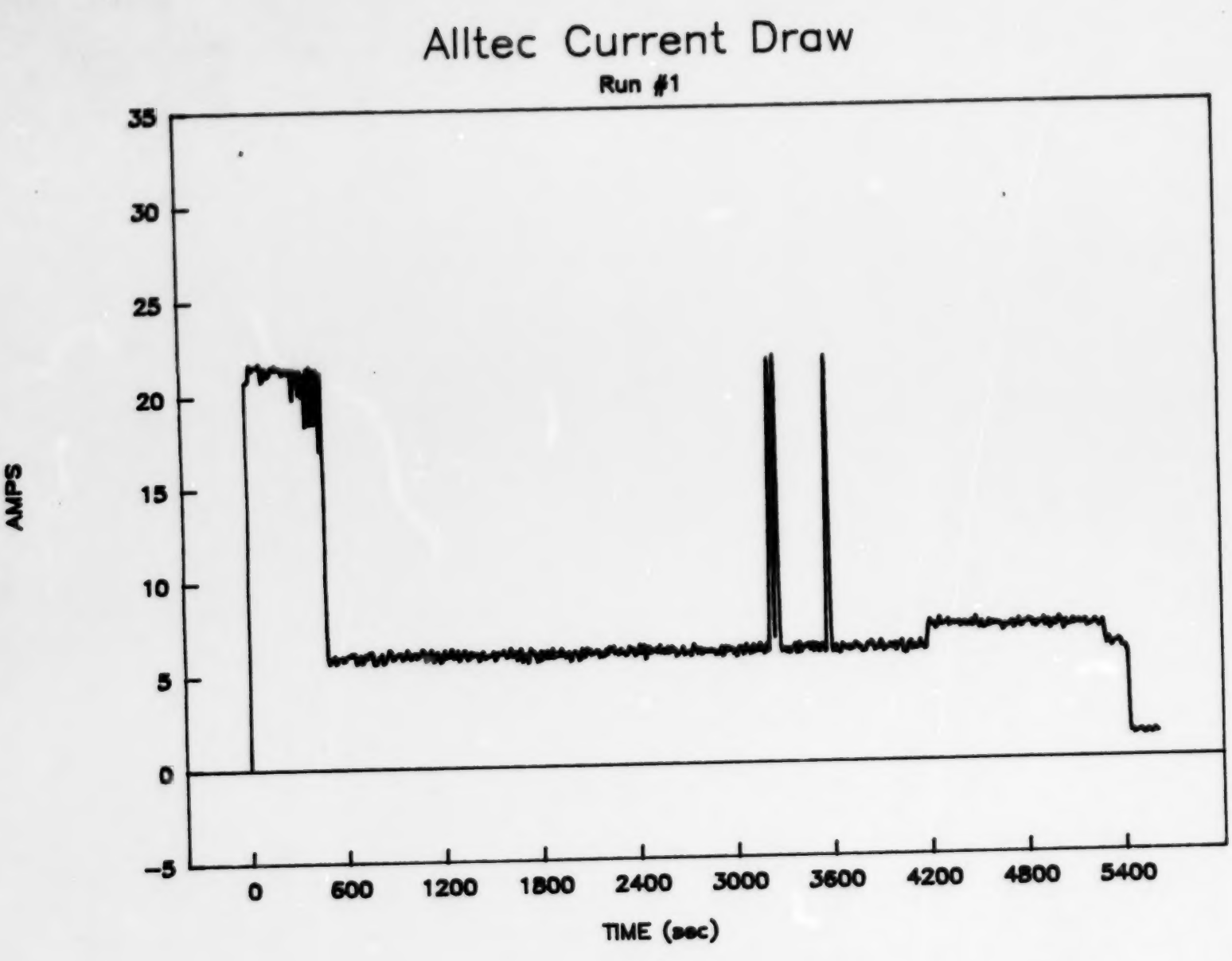

Figure 5/ Typical Current Curve – Alltec

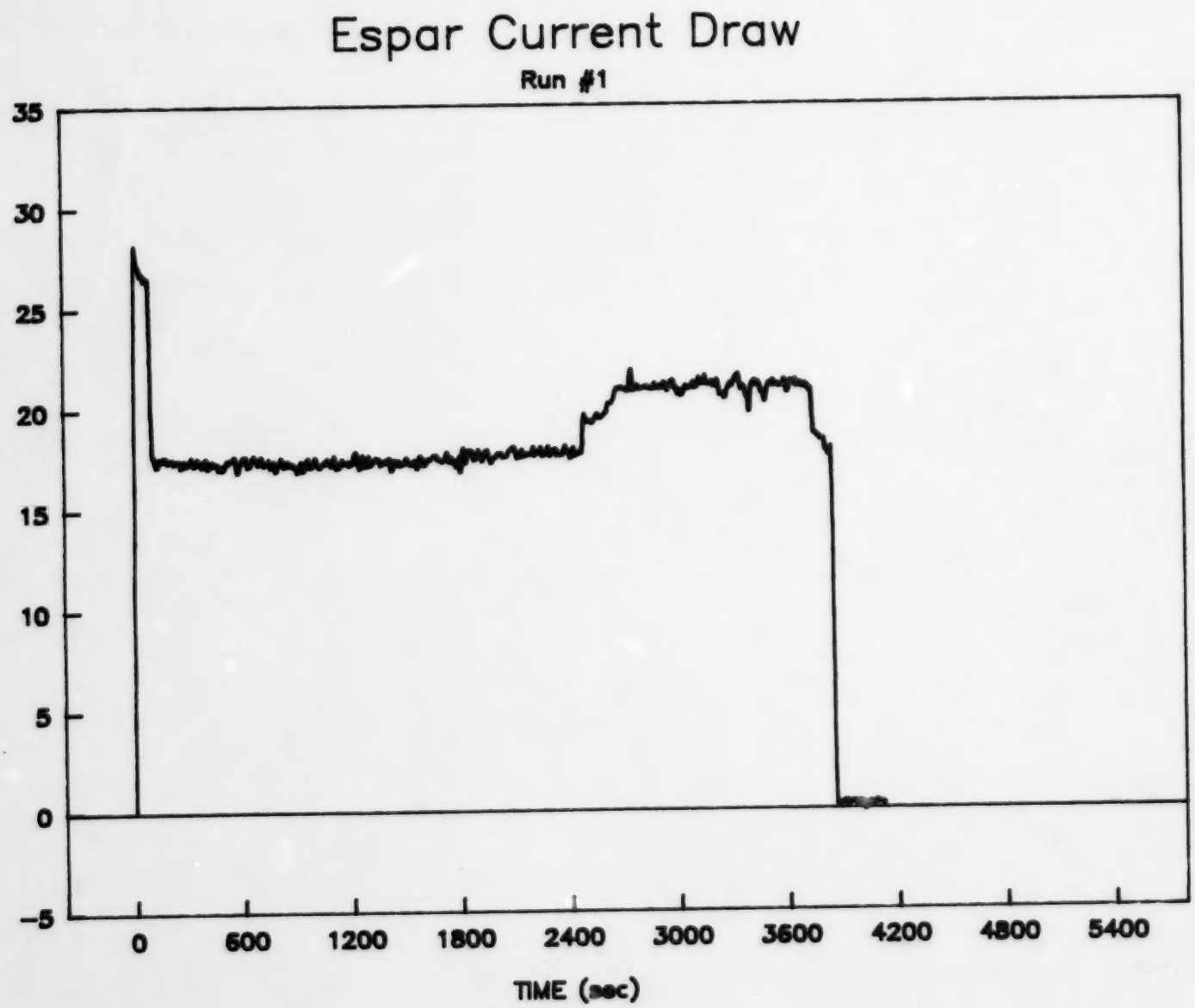

Figure 6/ Typical Current Curve – Espar

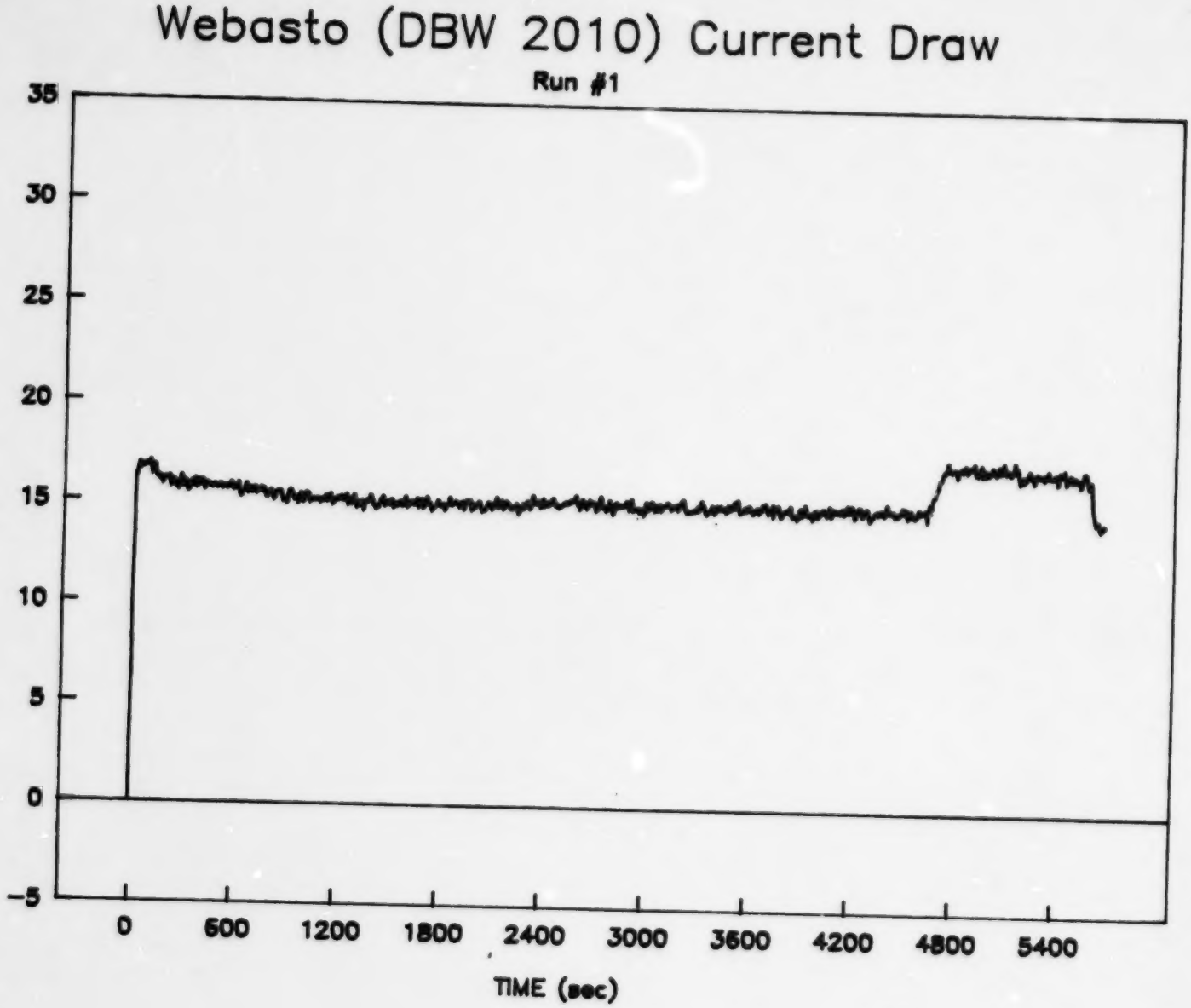

Figure 7/ Typical Current Curve – Webasto DBW 2010

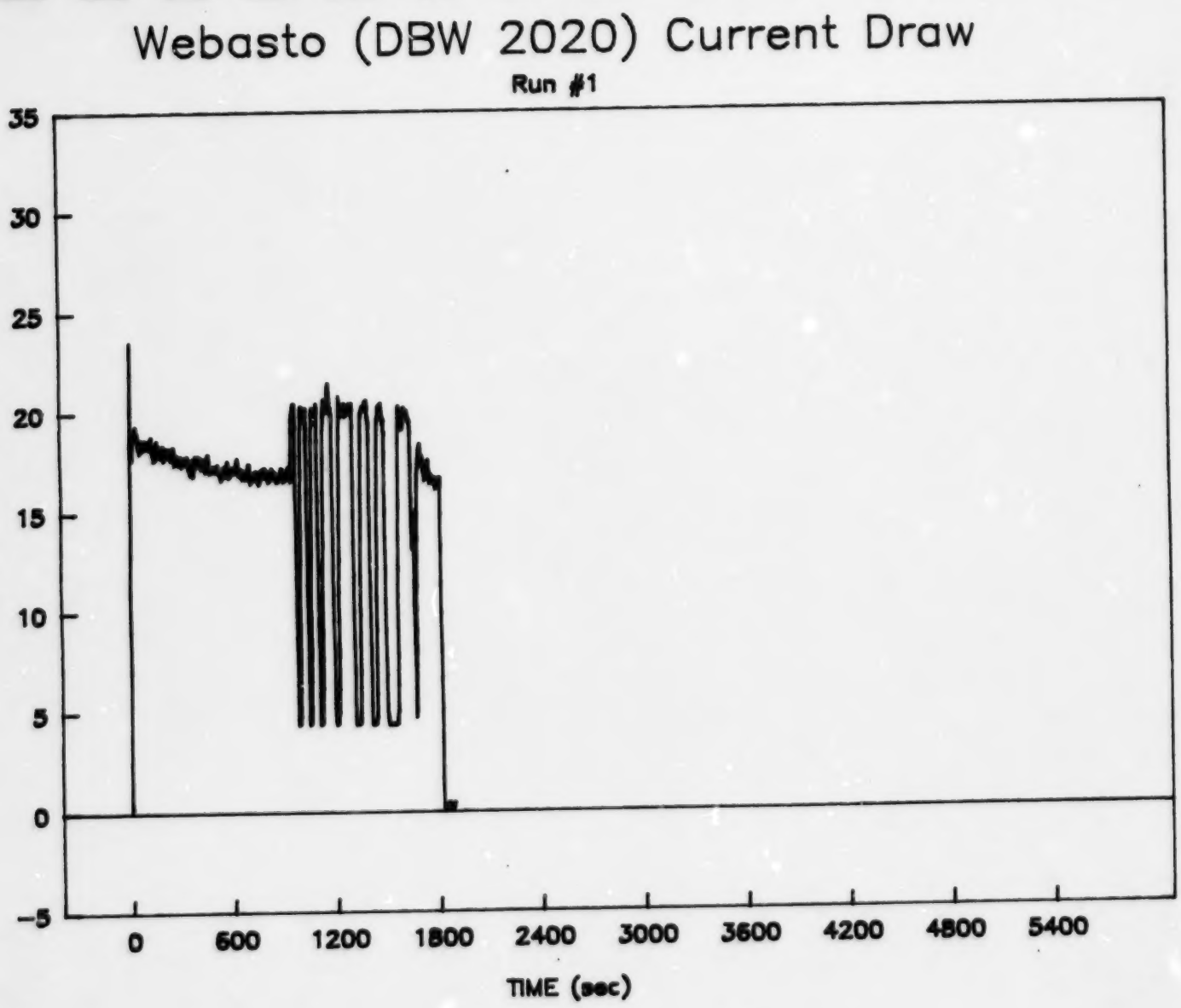

Figure 8/ Typical Current Curve – Webasto 2020